CHAPTER 13 Review

REFLECTING ON CHAPTER 13

- The neutron was discovered by James Chadwick.
- The particles in the nucleus are called "nucleons" and consist of protons and neutrons. Their number is indicated as the atomic mass number (A).
- The number of protons in the nucleus is indicated by the atomic number (Z).
- In a neutral atom, the number of electrons orbiting the nucleus equals the number of protons in the nucleus.
- A common mass unit for atoms and nuclei is the atomic mass unit (u).
  $$1\ \text{u} = 1.6605 \times 10^{-27}\ \text{kg}$$
- The mass defect is the difference between the separate total mass of the nucleons and the mass of the nucleus. It represents the binding energy for that nucleus.
- Nuclear fission is the splitting apart of a very large nucleus to produce two smaller nuclei plus several neutrons and energy.
- Nuclear fusion is the joining of two low-mass nuclei to form a larger nucleus.
- Henri Becquerel discovered radioactivity.
- Radioactivity consists of the emission of alpha particles (helium nuclei), beta negative particles (high-speed electrons), beta positive particles (high-speed positrons), and gamma rays (photons).
- Alpha, beta, and gamma radiation vary in their mass, charge, penetrating ability, and possible biological damage. The passage of any of these rays through matter leaves ions behind, so the radiation is called "ionizing radiation."
- Radiation can be detected by exposing film; causing ionization in matter by using, for example, the Geiger counter; and identifying the fluorescence or phosphorescence that radiation creates in some substances.
- Radioactivity has many uses, both medical and non-medical. For example, it is commonly used in smoke detectors.
- During any nuclear reaction the total atomic mass number (A) and the total atomic number (Z) remain unchanged.
- Transmutation is the conversion of one element into another.
- The rate of radioactive decay is indicated by the half-life of the radioisotope.
- Radioactive decay rates can be used to determine the age of ancient materials.
- The amount of a radioactive isotope remaining after a given time interval can be determined by using the following equation.
  $$N = N_0\left(\frac{1}{2}\right)^{\frac{\Delta t}{T_{\frac{1}{2}}}}$$
- A common unit in the field of radioactivity and radiation is the becquerel.
- Exposure to radiation can lead to various levels of sickness and, if severe enough, to death.
- Subatomic particles are grouped into three families — photons, leptons and hadrons. Hadrons consist of particles that are built from quarks.
- According to the standard model, forces are the result of the exchange of particles.
- The model of matter that involves particles as force carriers and the concept that all hadrons, such as protons and neutrons, are composed of quarks is known as the standard model.

Knowledge/Understanding

1. Use Einstein's theory to explain how the term "mass defect" refers to an amount of energy.
2. Outline the rationale for postulating the existence of a strong nuclear force as one of the fundamental forces of nature.
3. Compare the range of the field of influence of a strong nuclear force with that of an electromagnetic force when considering the effect of each on a proton near or in the nucleus of an atom.
4. Explain, with the aid of a series of sketches, the relative effects of an electromagnetic force and a strong nuclear force at several stages as a proton is propelled toward a nucleus in a fusion reaction.
5. Describe the characteristics of the three common forms of radioactivity.
6. Explain, based on our scientific understanding of radiation, why it is now useful to use the concept of a nucleon rather than a proton as a basic particle located in an atom's nucleus.
7. Explain why the daughter nuclei from fission reactions are likely to be radioactive.
8. Describe the concept of a *force carrier*. Outline how this concept is an explanatory device for outlining a scientific model in which mass and energy are simply different forms of the same phenomena.

Inquiry

9. The concept of antimatter has stimulated the imagination of many science fiction writers. Research and prepare a report of the scientific discoveries that led to the inclusion of antimatter particles in scientific models of matter.
10. Insight into nuclear structure can be gained by considering the binding energy per nucleon, $\Delta E/A$, for different elements. **(a)** Describe how the calculation of $\Delta E/A$ is used to indicate nucleons in a specific nucleus are tightly bound or loosely bound. **(b)** Calculate the binding energy, in both joules and MeV, for the following 12 elements: helium, carbon, neon, oxygen, chlorine, manganese, iron, cobalt, silver, gold, cesium, and uranium. In each case, divide the binding energy by the mass number, A.
(c) Write the equation for a common fusion reaction. Locate the position of the initial nuclei, by their nucleon number, on the graph on page 550. Locate the position of the fused nuclei on the graph. Describe the effect of fusion on the binding-energy-per-nucleon ratio.
(d) Write the equation for a common fission reaction. Locate on the graph on page 550 the position of the initial nuclei, by their nucleon number. Locate the position of the daughter nuclei on the graph. Describe the effect of fission on the binding energy per nucleon ratio.
(e) Locate on the graph the range of nucleon numbers of those elements that are more likely to undergo fusion and the range of nucleon numbers for those that are more likely to undergo fission.
11. Suppose an experiment is designed to allow continuous observation of a single atom of a certain radioactive material. If the half-life is 1.5 h, can the observer predict when the atom will decay?
12. Use conservation laws to determine which of the following reactions are possible. Explain your reasoning in each case.
(a) $p + p \rightarrow p + n + \pi^+$
(b) $p + p \rightarrow p + p + n$
(c) $p + p \rightarrow p + \pi^+$
(d) $p + p \rightarrow p + p + \pi^0$

Communication

13. Explain why neutrons are said to make better "nuclear bullets" than either protons or electrons.
14. Use the concepts of fission, fusion, and binding energies to provide a scientific explanation of what limits the size a stable nucleus.

Making Connections

15. Explain why, to date, nuclear reactors have been constructed to use fission, but none have been constructed to use fusion.

16. Food and surgical supplies are sometimes sterilized by radiation. What are the advantages and disadvantages of using this procedure rather than sterilization by heating?

17. In 1989, two scientists at the University of Utah announced to the public that they had produced excess energy in a fusion-like experiment at room temperatures. The experiment was dubbed "cold fusion" and the scientists thought they had identified a new, cheap energy source. However, other experimenters failed to reproduce the results of this experiment, so even today, most of the scientific community does not consider cold fusion as a real possibility. Research this episode of physics history and use it to discuss the roles of peer review and reproducing results in scientific methodology.

18. Prepare a report on how radioactive tracers are used to either **(a)** follow the path of rainwater through groundwater reservoirs to lakes, streams, and wells or **(b)** map ocean currents.

19. The word "radiation" strikes fear into the hearts of many people. In fact, many would not live anywhere near a nuclear power station. Gather information about common concerns and misconceptions about "radiation" by interviewing people and generating a file of newspaper articles. Identify four or five of the common issues. Write a scientific perspective on each. Make a recommendation of the safety features that you consider essential for operating a nuclear power station in such a way that you would feel comfortable living within a one kilometre radius of it.

Problems for Understanding

20. Determine the number of protons, neutrons and electrons in **(a)** a doubly ionized calcium ion $^{40}_{20}Ca^{++}$ **(b)** an iron atom $^{56}_{26}Fe$ **(c)** a singly charged chlorine ion $^{35}_{17}Cl^{-}$.

21. Calculate the binding energy for **(a)** $^{12}_{6}C$ with a atomic mass of 12.000 000 u **(b)** $^{133}_{55}Cs$ with a atomic mass of 132.905 429 u.

22. Write the equation for the alpha decay of thorium: $^{230}_{90}Th$.

23. What fraction of the original number of nuclei in a sample are left after **(a)** two half-lives, **(b)** four half-lives, and **(c)** 12 half-lives?

24. **(a)** How much energy is released when radium-226 (nuclear mass 225.977 09 u) alpha decays and becomes radon-222 (nuclear mass 221.970 356 u)? Answer in MeV.

(b) If the nucleus was initially at rest, calculate the velocities of the alpha particle and the radon-222 nucleus in part (a).

(c) What percentage of the total kinetic energy does the alpha particle carry away?

25. Hafnium-173 has a half-life of 24.0 h. If you begin with 0.25 g, how much will be left after 21 days?

26. How long will it take a 125 mg sample of krypton-89, which has a half-life of 3.16 min, to decrease to 10.0 μg?

27. A scientist at an archeological dig finds a bone that has a carbon-14 activity of 5.70×10^{-2} Bq. If the half-life of carbon-14 is 5.73×10^{3} a, what is the age of the bone? (Assume that the initial activity was 0.23 Bq.)

28. Suppose you began with a sample of 800 radioactive atoms with a half-life of 5 min.

(a) How many atoms of the parent nucleus would be left after 10 min?

(b) How many atoms of the daughter nucleus would be present after 10 min?

(c) How many atoms of the parent nucleus would be left after 25 min?

(d) How many atoms of the daughter nucleus would be left after 25 min?

(e) Write an equation to determine the number of daughter nuclei present at any time.

29. In radioactive dating, ratios of the numbers of parent and daughter nuclei from the same decay chain, such as uranium-238 and lead-206, are determined. Assume that when the sample formed, it contained no daughter nuclei. Consider the analyses of three different rock samples that have been determined to have ratios of uranium-238 to lead-206 of 1.08:1, 1.22:1, and 1.75:1.
   (a) Using the results of the previous question, write an equation for the ratio of the number of uranium-238 atoms to lead-206 atoms present at any time. (Hint: the initial number of uranium-238 atoms will divide out.)
   (b) Solve the above equation for time, and determine the ages of the three samples. (The half-life of uranium-238 is 4.5×10^9 a.)
   (c) Explain whether these samples could have been taken from an area where the rock solidified all at once.
   (d) Intuitively, what conclusion can you draw if you measure a ratio of less than one?
30. What is the wavelength of each of the two photons produced in electron-positron annihilation?
31. Heavy water used in the Sudbury Neutrino Observatory is made up of oxygen and deuterium, a radioactive isotope of hydrogen (see Not Your Average Observatory, page 554). One of the reactions that physicists at the observatory are trying to detect is $\nu_e + {}^2_1\text{H} \rightarrow p + p + e^-$, where ν_e is an electron-neutrino. For this reaction to be observed, the neutrino's energy must be greater than the binding energy of a deuterium atom.
   (a) Given that the nuclear mass of deuterium is 2.013 553 u, calculate the minimum neutrino energy for this reaction to occur.
   (b) If 95.0% of the neutrino's kinetic energy goes into the kinetic energy of the produced electron, calculate the speed of the electron. (Hint: The electron's speed is relativistic.)
   (c) Compare the electron's speed with the speed of light in water.
32. Analyze the following reactions in terms of their constituent quarks.
   (a) $n \rightarrow p + e^- + \overline{\nu}_e$
   (b) $\gamma + n \rightarrow \pi^- + p$